

# Baryon Resonances in the Double Pion Channel at Jefferson Lab (CEBAF): Experimental and Physical Analysis Status and Perspectives

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**Abstract.** The excited baryons made from light quarks are known to decay in single meson as well as in multimeson final states. In particular, the double pion production is sensitive to many excited states of proton and neutron. Quark models predict such decays and also that some resonances could decouple from single meson channels and appear predominantly in multipion production reactions via electromagnetic excitation: the so called “missing resonances”. These issues are part of the CLAS collaboration scientific program at Jefferson Laboratory, where the reaction  $eN \rightarrow e'N\pi\pi$  is being used in the mass region between threshold and 2.2 GeV to investigate baryon resonances and test quark models. In this contribution I will present a framework for the physical interpretation of the data, especially focusing on the approach developed by the Genova-Moscow collaboration. Some very preliminary raw mass distributions collected with CLAS are then shown.

## 1 Introduction

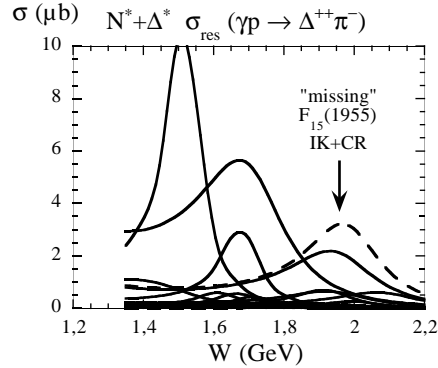
As established in several years of experimental and theoretical investigation[1, 2], mesons and baryons appear to gather in mass multiplets that can be interpreted as the manifestation of ground state and excitation spectrum of a system with internal structure. The multiplet structure is seen as the reflection of symmetry properties of the Hamiltonian describing the system. Looking at the ground state, one can see that baryons are organized in an octet of spin 1/2 particles containing proton and neutron, while the well-known  $\Delta(1232)$  excitation of the nucleon appears to be member of a spin 3/2 decuplet. Octet and decuplet can be in turn put together in a 56-plet, where the 56 comes from spin states counting. Octet and decuplet naturally arise assuming a Hamiltonian symmetric under the “flavour” group  $SU(3)$  describing the basic  $u, d, s$

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lightest quarks. The spin  $SU(2)$  symmetry does the remaining job, leading to the 56-plet of  $SU(3) \otimes SU(2)$ . Addition of internal quark motion leads to a sequence of orbital bands, like those obtained using an harmonic oscillator confining potential. Flavour symmetry breaking, basically due to the mass difference between  $u, d$  and  $s$  quarks, leads to the splitting between baryon states with different strangeness. Moreover, to explain the nucleon- $\Delta$  300 MeV mass difference, spin-spin interactions are introduced: they break  $SU(2)$  symmetry, producing a configuration mixing and shifting the  $\Delta$  mass from that of the nucleon, as required. Finally, the color degree of freedom is assumed to be frozen in singlet states, such that the resulting hadrons are white, or colorless.

The use of any quark model incorporating the basic features of approximate  $SU(6)$  symmetry with explicit flavour-breaking terms and spin-spin interaction, with a spatial wavefunction obtained from some confining potential, is able to account quite reasonably for some general properties of baryon states observed experimentally. In particular the ground state and the first excited states are usually well accounted for as far as their main static properties are concerned. However, besides the well-known discrepancies between electromagnetic properties like calculated and measured form factors, there is also a major issue regarding the number of states: the symmetric quark model predicts a number of states in the second orbital band which is higher than what seen in experiments. This is referred to as the problem of “missing states” and stimulated different formulations: in quark models[3] with hyperfine mixing and explicit meson couplings, it turns out that some states could have a very weak pion coupling, while decaying predominately in multipion channels, as observed on the other hand in many high-lying measured states; as the sources of experimental information are mainly reactions with the pion as projectile or the single pion as final channel, photoproduced off the nucleon, it would not be surprising to find that baryon states with very small pion coupling were absent from those data sets. Other models[4, 5, 6, 7] based on various meson creation assumptions found similar results. An alternative explanation given for instance by the Quark Cluster Model [8] is on the contrary based on a reduction of the spatial degrees of freedom. From this introduction, it is quite clear that to test different model pictures it is necessary to increase the experimental information on the multipion production, but using an electromagnetic probe, to avoid the weak pion coupling situation that could affect hadron facilities, without forgetting that the experimental investigation is made difficult by the often large non-resonant background, as discussed in the following sections. Needless to say, Jefferson Lab with the CLAS detector[9, 10], with its high luminosity, acceptance and good momentum resolution, is the ideal place for performing such kind of studies: experiments[11] are currently conducted at Jefferson Lab with namely this goal.



**Figure 1.** Breit-Wigner cross section in  $\gamma p \rightarrow \Delta^{++} \pi^-$  reaction for known resonances[17] and for a particular missing state[3,6].

## 2 Phenomenology

Main contributions to the double pion production are isobar channels like  $\Delta(1236)\pi$  and  $\rho N$ [12]:  $eN \rightarrow e' \Delta \pi \rightarrow e' N' \pi \pi$ ,  $eN \rightarrow e' \rho N \rightarrow e' N' \pi \pi$ . All isobar production channels can proceed through continuum processes, or through the excitation of baryon resonances with a cascade like  $eN \rightarrow e' N^* \rightarrow e' \Delta \pi \rightarrow e' N' \pi \pi$ . The double pion production data come mainly from bubble chamber experiments with real photons[12, 13], where data about various charge channels were collected. Another experiment at DESY[14] measured the electroproduction of  $p\pi^+\pi^-$  off the proton with very poor statistics and large binning. Recent photoproduction measurements up to slightly above the  $D_{13}(1520)$  have been performed at Mainz[15, 16], using the DAPHNE large angle detector, while data in a wider energy range have been collected in Bonn using the SAPHIR[16, 17] detector. In fig. 1, data[18] about known resonance excitations (full curves) together with predictions[3, 6] for missing states photo-excitation and subsequent decay (dashed curve) are used to give an estimate of the effect of a missing state: we can expect that the cross section should manifest some sensitivity.

## 3 Data analysis and interpretation

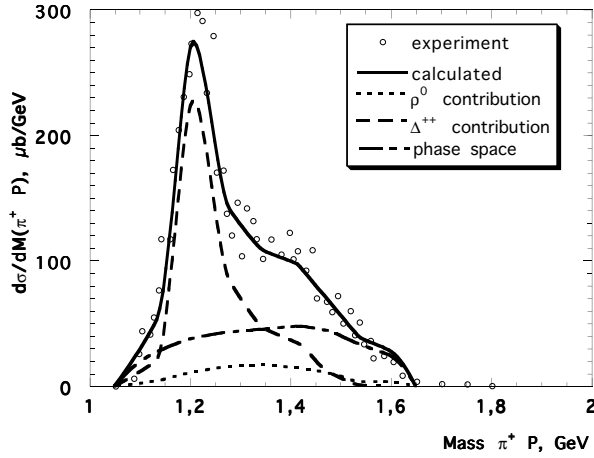
At new facilities like CLAS, high luminosity, large geometrical acceptance, good efficiency for both charged and neutral particles are opening a new era of unprecedented accuracy in the measurement of exclusive reactions, allowing a more sophisticated data analysis with respect to the past. The main feature evident from all the two pion production data collected in the past experiments[12, 14, 15, 16] is the presence of the isobar "quasi-two-body" states  $\Delta\pi$  and  $\rho N$ . A typical approach for separating such different isobar contribu-

tions is to simply fit their bumps in the invariant masses, obtaining approximate cross sections. This was the data analysis adopted in most of the past experiments with electromagnetic probes[12, 14], being interested essentially in the gross features and being the data affected by high statistical uncertainty. However, the correct description of a three-body collision is based on five independent kinematical variables in the most general case[19] and moreover the isobar quasi-two-body production and subsequent decay involves all of them[20]. Investigations of double pion production from pion beams have been in fact conducted using isobar model approaches containing the partial wave expansion for each quasi-two-body process and fitting the data in the full kinematical space[21]. Any resonance analysis with the goal of extracting the baryon resonance decay branches in a quasi-two-body channel or the product of the e.m. transition matrix elements with the strong decay one (the “electrostrong properties” [22]), in a way as model independent as possible, needs such an isobar partial wave separation from the data as an input, similar to what done in previous analysis[23, 24]. Therefore in a preliminary simple study done on the  $\Delta\pi$  channel, pseudo-events were generated using only the geometrical partial wave expansion[25], with no explicit dynamics, then refitted to retrieve the partial wave coefficients. The outcome was that even in this simple case the fitting code was not able to retrieve the large number of independent helicity amplitudes that arise with increasing angular momentum. Different solutions could be in principle pursued: one way is to add polarisation observables, in order to have a more constrained fit; a second possibility is to use orbital waves constrained by threshold behavior; a further possibility is to use simple model assumptions for the continuum and the resonances. In fact, it is important to consider that the  $N^*$  study in two-pion production is affected by strong non-resonant processes and therefore model-independent methods of analysis may be not effective. For all these reasons the choice in the Genova-Moscow collaboration[26] was to give up the requirement of minimal model dependence and use some partial wave content suggested from a model as input to the analysis, as described in the next section.

#### 4 Our approach for the quasi-two-body channels

After the old work that followed the bubble chamber first experiments[12, 27], recent approaches to describe double pion photoproduction have been presented in a few papers[28, 29] based on a variety of tree-level diagrams and a few baryon resonances. The restricted number of resonances included however makes them strictly applicable only for  $W$  lower than 1.6 - 1.7 GeV; moreover non-resonant terms have been evaluated only at the photon point and not always corrected for unitarity absorption effects.

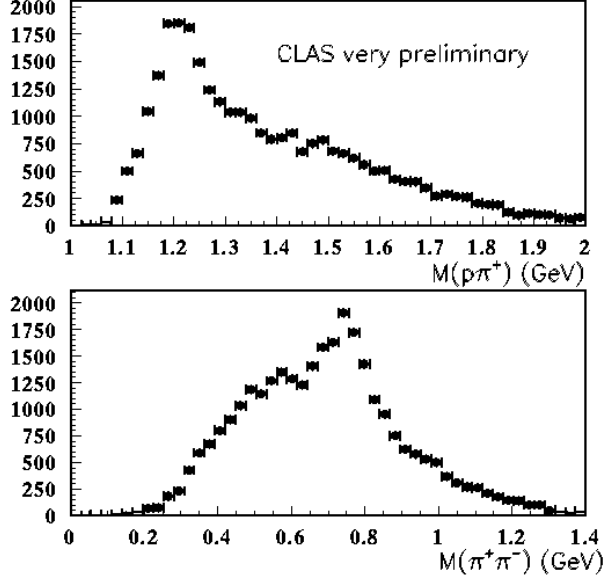
The Genova-Moscow approach to calculate cross sections is described in more detail in [30, 26]. I report here the general features. Following the data, we also use a coherent superposition of  $\gamma_{r,v}p \rightarrow \pi^- \Delta^{++1}$  and  $\gamma_{r,v}p \rightarrow \rho p^1$  quasi-two-body subchannels. All remaining processes are described in phase



**Figure 2.** Invariant mass distribution for  $p\pi^+$  pair from SAPHIR data[36] and the Genova-Moscow fit: the meaning of the different contributions is reported in the picture legend .

space approximation. The  $\gamma_{r,v}p \rightarrow \pi^-\Delta^{++}$  reaction is described by a superposition of  $N^*$ ,  $\Delta^*$  excitation in s-channel and a minimal set of non-resonant processes obeying gauge invariance conditions, similar to what done in the previous literature[12, 27]. Non-resonant amplitudes are derived from an effective Lagrangian[27], as done for other meson production channels[31]. New features of this approach are: (1) the treatment of particle's off-shell behaviour through introduction of vertex functions that result from a combination of electromagnetic form factors and strong form factors specified via a cut-off parameter[30, 26]; data[32] have been used to determine part of them, while the remaining terms in the calculation were derived imposing gauge invariance[30, 26]; (2) the initial and final state absorption due to competitive channels follows [33], but the elastic hadronic amplitudes are reconstructed using resonant contributions taken from [34], plus a smooth background parametrised in the same fashion of [35]. It is important to stress here that “missing” resonances with strong two pion coupling should be introduced consistently in both the e.m. amplitudes as well as in the absorption: this evaluation is currently under way in our Genova-Moscow collaboration. Results from this calculation for  $\gamma_{r,v}p \rightarrow \pi^-\Delta^{++}$  reaction are extensively reported in the contribution presented by V. Mokeev at this Workshop. Basically, main findings are that leaving the absorption as a free parameter it is possible to get a very good fit of the data, but resonance extraction becomes more uncertain; using the above parametrisation of initial and final state interaction, data are not completely reproduced[26], but this discrepancy opens room to

<sup>1</sup>Indexes r,v stand for real and virtual photons respectively.



**Figure 3.** Invariant mass distributions for the  $p\pi^+$  (top) and the  $\pi^+\pi^-$  (bottom) pairs from CLAS for  $W_L 1.7$  GeV. These are raw data without any energy or momentum transfer binning; acceptance correction were also not applied.

interesting effects like possible missing states contributions.

As the experiment does not measure isobar production directly of course, but only the two pion final state, in order to have a complete tool for the analysis next step was to merge together the  $\Delta\pi$  and  $\rho N$  production channels plus a phase space in a full three-body calculation. A new feature of the Genova-Moscow approach in this respect is the introduction of decay strong form factors for the  $\Delta$  and  $\rho$  decay[36]. In fig. 2, I present an example of the results obtained fitting invariant mass distributions from recent photoproduction data[17]. The fit is pretty good, therefore providing a promising tool for a quite reliable extraction of the different isobar components in the reaction.

## 5 A quick look at the first CLAS data

In this talk I showed also some very preliminary data from CEBAF-CLAS experiment E-93-006. In fig. 3 a snapshot from a sample of CLAS data is reported, showing the invariant mass distributions for the  $p\pi^+$  and the  $\pi^+\pi^-$  pairs for  $W_L 1.7$  GeV. The data were neither binned in  $W$  nor in  $Q^2$  and they were not corrected for the detector acceptance; therefore they represent only the raw output from CLAS with the intent of giving essentially an idea of its capabilities. However, the contributions of the  $\Delta^{++}$  and of the  $\rho^0$  meson, respectively, are recognizable. The data already collected contain about an order of magnitude more events and nearly the same amount will be accumulated

in other planned running periods, therefore allowing a quite large binning and investigation of details such as decay angular distributions with much higher accuracy than the past.

## 6 Summary and conclusions

New experiments like those currently conducted at Jefferson Laboratory are providing a wealth of new accurate data about exclusive electromagnetic reactions. Two pion production is one of the main subjects of investigation, being related to baryon resonances coupled to this channel. A specific approach for the isobar channels that appear in the two pion production has been developed in the framework of the Genova-Moscow collaboration, taking particular care about the  $\Delta\pi$ , channel description, especially concerning initial and final state absorption, gauge invariance, vertex functions and multiple resonances.  $\rho$  meson production was instead described through a simple diffraction ansatz. These calculations are able to give good account of existing data about differential cross sections and invariant mass distributions, therefore promising to allow a quite complete data analysis and a first evaluation of resonance contributions. In the first data from CLAS it is already possible to recognize the isobar formation with good statistics, opening the route to more detailed studies of the involved dynamics.

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